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American National Standard

Standard for Design and Specifications of Gearboxes for Wind Turbines

ANSI/AGMA/AWEA 6006-A03

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American National Standard

Standard for Design and Specification of Gearboxes for Wind Turbines ANSI/AGMA/AWEA 6006–A03

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Approved January 9, 2004

ABSTRACT

This standard is intended to apply to wind turbine gearboxes. It provides information for specifying, selecting, designing, manufacturing, procuring, operating and maintaining reliable speed increasing gearboxes for wind turbine generator system service.

Annex information is supplied on: wind turbine architecture, wind turbine load description, quality assurance, operation and maintenance, minimum purchaser gearbox manufacturer ordering data, lubrication selection and monitoring, determination of an application factor from a load spectrum using the equivalent torque, and bearing stress calculations.

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Foreword

[The foreword, footnotes and annexes, if any, in this document are provided for informational purposes only and are not to be construed as a part of ANSI/AGMA/AWEA 6006–A03, *Standard for Design and Specification of Gearboxes for Wind Turbines*.]

The operation and loading of a wind turbine speed increasing gearbox is unlike most other gear applications. The intent of this standard is to describe the differences. Much of the information is based on field experience. This standard is a tool whereby wind turbine and gearbox manufacturers can communicate and understand each other's needs in developing a gearbox specification for wind turbine applications. The annexes present informative discussion of various issues specific to wind turbine applications and gear design.

A combined committee of AWEA and AGMA members representing wind turbine manufacturers, operators, researchers, consultants, and gear, bearing and lubricant manufacturers were responsible for the drafting and development of this standard.

The committee first met in 1993 to develop AGMA/AWEA 921–A97, *Recommended Practices for Design and Specification of Gearboxes for Wind Turbine Generator Systems*. The AGMA Information Sheet was approved by the AGMA/AWEA Wind Turbine Gear Committee on October 25, 1996 and by the AGMA Technical Division Executive Committee on October 28, 1996. This standard supersedes AGMA/AWEA 921–A97.

The first draft of ANSI/AGMA/AWEA 6006–A03 was made in March, 2000. It was approved by the AGMA membership in October, 2003. It was approved as an American National Standard on January 9, 2004.

Suggestions for improvement of this standard will be welcome. They should be sent to the American Gear Manufacturers Association, 500 Montgomery Street, Suite 350, Alexandria, Virginia 22314.

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American National Standard – Standard for Design and Specification of Gearboxes for Wind Turbines

1 Scope

This standard applies to gearboxes for wind turbines with power capacities ranging from 40 kW to 2 MW. It applies to all parallel axis, one stage epicyclic, and combined one stage epicyclic and parallel shaft enclosed gearboxes. The provisions made in this standard are based on field experience with wind turbines having the above power capacities and configurations.

Guidelines of this standard may be applied to higher capacity wind turbines provided the specifications are appropriately modified to accommodate the characteristics of higher capacity wind turbines.

Life requirements apply to wind turbines with a minimum design lifetime of 20 years.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below.

AGMA 901-A92, *A Rational Procedure for Preliminary Design of Minimum Volume Gears*

AGMA 913-A98, *Method for Specifying the Geometry of Spur and Helical Gears*

AGMA 925-A03, *Effect of Lubrication on Gear Surface Distress*

AMS 2301, *Aircraft quality steel cleanliness, magnetic particle inspection procedure*

ANSI Y12.3-1968, *Letter symbols for quantities used in mechanics of solids*

ANSI/AGMA 1012-F90, *Gear Nomenclature, Definitions of Terms with Symbols*

ANSI/AGMA 2101-C95, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth*

ANSI/AGMA 6000-B96, *Specification for Measurement of Linear Vibration on Gear Units*

ANSI/AGMA 6001-D97, *Design and Selection of Components for Enclosed Gear Drives*

ANSI/AGMA 6025-D98, *Sound for Enclosed Helical, Herringbone, and Spiral Bevel Gear Drives*

ANSI/AGMA 6110-F97, *Standard for Spur, Helical, Herringbone and Bevel Enclosed Drives*

ANSI/AGMA 6123-A88, *Design Manual for Enclosed Epicyclic Metric Module Gear Drives*

ANSI/AGMA 9005-E02, *Industrial Gear Lubrication*

ANSI/AGMA/ISO 1328-1, *Cylindrical Gears – ISO System Of Accuracy – Part 1: Definitions and Allowable Values of Deviations Relevant to Corresponding Flanks of Gear Teeth*

ASTM A534, *Standard specification for carburizing steels for anti-friction bearings*

Det Norske Veritas Classification AS, Classification Notes No. 41.2, *Calculation of Gear Rating for Marine Transmissions*, July 1993

DIN ISO 281 Bbl. 4:2003, *Dynamische Tragzahl und nominelle Lebensdauer – Verfahren zur Berechnung der modifizierten Referenzlebensdauer für allgemein belastete Wälzlager (Dynamic load ratings and life – Method for calculation of the modified reference rating life for generally loaded rolling bearings)*¹⁾

DIN 743:2000, *Tragfähigkeitsberechnung von Wellen und Achsen (Calculation of load capacity of shafts and axles)*

¹⁾ English translation available as ISO TC 4/SC 8 N254a

DIN 7190:2001, *Interference fits – Calculation and design rules*

ISO 76:1987, *Rolling bearings – Static load ratings*

ISO 281:1990, *Rolling bearings – Dynamic load rating and rating life*

ISO R773:1969, *Rectangular or square parallel keys and their corresponding keyways (dimensions in millimeters)*

ISO 4406:1999 (SAE J1165), *Hydraulic fluid power – Fluids – Method for coding the level of contamination by solid particles*

ISO 6336– 1: 1996, *Calculation of load capacity of spur and helical gears– Part 1: Basic principles, introduction and general influence factors*

ISO 6336– 2: 1996, *Calculation of load capacity of spur and helical gears– Part 2: Calculation of surface durability (pitting)*

ISO 6336– 3: 1996, *Calculation of load capacity of spur and helical gears– Part 3: Calculation of tooth bending strength*

ISO 6336–5: 1996, *Calculation of load capacity of spur and helical gears– Part 5: Strength and quality of materials*

ISO/CD 6336–6²⁾, *Calculation of load capacity of spur and helical gears – Part 6: Calculation of service life under variable load*

ISO 8579–1:2002, *Acceptance code for gears – Part 1: Determination of airborne sound power levels emitted by gear units*

ISO 8579–2:1993, *Acceptance code for gears – Part 2: Determination of mechanical vibration of gear units during acceptance testing*

ISO/TR 13593:1999, *Enclosed gear drives for industrial applications*

ISO/TR 13989–1:2000, *Calculation of scuffing load capacity of cylindrical, bevel and hypoid gears – Part 1: Flash temperature method*

ISO 14104:1995, *Gears – Surface temper etch inspection after grinding*

ISO/TR 14179–1:2001, *Gears – Thermal capacity – Part 1: Rating gear drives with thermal equilibrium at 95°C sump temperature*

3 Definitions and symbols

The terms used, wherever applicable, conform to ANSI/AGMA 1012–F90, and ANSI Y12.3–1968.

3.1 Symbols

The symbols, terms and units used in this standard are shown in table 1.

NOTE: The symbols and terms contained in this document may vary from those used in other AGMA standards. Users of this standard should assure themselves that they are using these symbols and terms in the manner indicated herein.

3.2 Wind turbine terms

active yaw: A system to rotate the nacelle relative to the changing direction of the wind. See passive yaw.

airfoil: Two dimensional cross section of a blade.

annual average wind speed: The time averaged, mean, horizontal wind speed for one calendar year at a particular site and a specified height.

annual average turbulence intensity: A measure of the short-time and spatial variation of the inflow wind speed about its long time average.

availability: The ratio of the number of hours that a turbine could operate to the total number of hours in that period, usually expressed as a percentage. Downtime due to faults or maintenance (scheduled or otherwise) generally make up the unavailable time.

bedplate: In a modular system, the structure that supports the drive train components and nacelle cover. Also called a main frame.

blade: The component of the rotor that converts wind energy into rotation of the rotor shaft.

brake: A device capable of stopping rotation of the rotor or reducing its speed.

certification: Procedure by which a third party gives written assurance that a product, process or service conforms to specified requirements, also known as conformity assessment.

certification standard: Standard that has specific rules for procedures and management to carry out certification of conformity.

control system: A system that monitors the wind turbine and its environment and adjusts the wind turbine to keep it within operating limits.

²⁾ Presently at the development stage.

Table 1 - Symbols

Symbol	Term	Units	Where first used
C	Basic dynamic load rating	N	Eq 1
C_0	Basic static load rating	N	5.1.3.1
f_{ma}	Mesh misalignment	--	5.1.1.3
K_A	Ratio between the equivalent and the nominal torque	--	5.1.1.5
$K_{H\beta}$	Load distribution factor	--	5.1.1.2
K_{lc}	Ratio of maximum contact pressure to contact pressure for line contact without misalignment	--	Eq 4
K_m	Ratio of maximum contact pressure with misalignment to maximum contact pressure without misalignment	--	Eq 4
K_v	Dynamic factor	--	5.1.1.1
k	Load sharing factor for the maximum loaded roller	--	Eq 2
L_{adv}	Combined advanced rating life	hours	5.1.3.2.3
$L_{adv,i}$	Advanced rating life on the i th load level	hours	Eq 5
L_{h10}	Basic rating life	hours	Eq 1
L_{we}	Effective roller length	mm	Eq 3
L_{10r}	Combined nominal reference rating life	hours	5.1.3.2.3
n	Rotational speed	rpm	Eq 1
P	Dynamic equivalent bearing load	N	Eq 1
P_0	Equivalent static bearing load	N	5.1.3.1
P_t	Rated power of wind turbine	kW	Eq 6
p	Exponent in bearing life equation	--	Eq 1
p_{line}	Contact pressure for line contact	MPa	Eq 3
p_{max}	Maximum contact stress	MPa	Table 3
Q	Single roller maximum load for a clearance free bearing	N	Eq 2
Q_{ty}	Recommended oil quantity	liters	Eq 6
q_i	Time share on the i th load level	--	Eq 5
R_a	Roughness average	μm	5.2.8.2
R_z	Mean peak-to-valley height	μm	5.2.8.2
S_F	Safety factor for bending strength	--	5.1.1.4
S_H	Safety factor for pitting resistance	--	5.1.1.4
Y_N	Stress cycle factor for bending strength	--	5.1.1.4
Y_{NT}	Life factor for bending	--	5.1.1.5
Z	Total number of rolling elements	--	Eq 2
Z_N	Stress cycle factor for pitting resistance	--	5.1.1.4
Z_{NT}	Life factor for pitting resistance	--	5.1.1.5
α_0	Nominal contact angle of the bearing	degrees	Eq 2
$\Sigma\rho_{line}$	Curvature sum for line contact	--	Eq 3
κ	Viscosity ratio	--	5.1.3.3

cut-in wind speed: The minimum wind speed at hub height at which the control system calls for the turbine to produce power.

cut-out wind speed: The maximum wind speed at hub height at which the control system calls for the turbine to produce power.

damped yaw: A device used to slow yaw motions.

design life: The period of real time that the system is expected to continue functioning. Includes operating, idling and stopped time.

downwind turbine: A HAWT where the wind passes the tower before the rotor.

dynamic equivalent bearing load: A hypothetical load, constant in magnitude and direction, acting radially on radial bearings or axially on thrust bearings, which if applied, would have the same influence on bearing life as the actual loads to which the bearing is subjected.

emergency shutdown: A rapid shutdown of the wind turbine triggered by the control system, a protection system or manual intervention.

extreme load: The extreme load is that load from any source, either operating or non-operating, that is the largest single load that the gearbox will see during its design life beyond which the gearbox no longer satisfies the design requirements. This load can be either forces, moments, torques, or a combination of the three. This load, supplied by the wind turbine manufacturer, includes all partial load safety factors.

extreme torque: The extreme torque is that torque from any source that is the largest single torque that the gearbox will see during its design life beyond which the gearbox no longer satisfies the design requirements.

extreme wind speed: The highest short-term average wind speed that is likely to be experienced by the wind turbine during its service lifetime. It is typically based on statistical estimates of the long term behavior of the wind speed.

feathering: In a variable pitch HAWT, the action of pitching the blades to a minimum power production position.

fixed pitch rotor: A rotor with blades that do not change pitch during operation. The pitch angle of the rotor blades may be changed manually for site specific or seasonal wind spectrum changes.

free yaw: See passive yaw.

HAWT: Horizontal axis wind turbine. The rotational axis of the rotor is approximately parallel to the horizon.

horizontal axis: The axis of rotor rotation is approximately parallel to the horizon.

hub height: For a HAWT, the height to the center of the rotor.

hub: The structure that attaches the blades to the rotor shaft.

idling: Operating condition where the rotor is rotating and the generator is not producing power.

input or mechanical power: The mechanical power measured at the gearbox low speed shaft or the wind turbine rotor shaft.

input shaft: See rotor shaft.

integrated system: A system architecture in which the gearbox housing supports the rotor directly, and in some cases, the generator(s) and other components. See modular system.

lock: The use of a mechanical device to prevent movement of the rotor or yaw drive.

main frame: See bedplate.

main shaft: See rotor shaft.

maximum operating load: The maximum operating load is the highest load in the load spectrum.

maximum power: The highest level of net electrical power delivered by a wind turbine in normal operation.

Miner's sum dynamic equivalent bearing load: The dynamic equivalent bearing load obtained by combining loads and speeds in a wind spectrum using Miner's rule.

modular system: A system architecture in which the rotor shaft assembly, gearbox, generator(s) and, possibly, a yaw drive, are separate components mounted to a common main frame. See integrated system.

motoring: Operating condition where the generator is consuming power.

nacelle: The structure that contains the drive train and other components located at the top of a HAWT.

nacelle cover: The housing that covers the nacelle.

nominal speed: The gearbox low speed shaft speed at which mechanical power is defined.

non-rotating: Operating condition where the rotor is not rotating.

normal shutdown: Transitional operating condition where the rotor decelerates from operating speed to standstill or idling and the generator ceases to generate power.

operational wind speed range: The range of wind speeds between the cut-in and the cut-out speed.

output shaft: See high speed shaft.

parked: Operating condition where the rotor is not rotating because the parking brake is applied.

parking brake: A device capable of preventing rotor rotation.

passive yaw: The forces of the wind are used to align the nacelle (rotor disk) relative to the changing direction of the wind. See active yaw.

pitch: The angular position of the rotor blades about their long axis.

pitch control: Rotor shaft torque limiting is accomplished by actively adjusting the pitch.

preventive maintenance: Scheduled work intended to prevent failure or unscheduled repairs.

rated power: The continuous electrical power output assigned by the WTGS manufacturer that the wind turbine is designed to achieve under normal operating conditions at rated wind speed.

rated wind speed: The specified wind speed, assigned by the WTGS manufacturer, at which the rated power is produced.

rotor: The hub/blade assembly.

rotor bearing(s): The bearing(s) that supports the rotor shaft.

rotor diameter (horizontal axis): Diameter of the disk swept by the rotation of the blades.

rotor shaft: The shaft that supports the rotor and transmits the rotor torque to the gearbox. Also called the main shaft.

rotor speed: The rotational speed of the wind turbine rotor about its axis, in revolutions per minute.

stall control: Rotor shaft torque limiting is accomplished by aerodynamic design (airfoil selection, blade taper, blade twist, blade pitch, rotor speed).

standstill: See non-rotating.

startup: Transitional condition where the rotor accelerates from standstill or idling to operating speed and the generator begins to generate power.

tower: The structure that supports the nacelle in a HAWT.

turbulence intensity: A statistical measure of the variation in the wind speed. The ratio of the standard deviation of the wind speed to the mean wind speed.

upwind turbine: A HAWT where the wind passes the rotor before the tower.

variable pitch rotor: A rotor whose blade pitch can be varied during operation. The pitch angle may be actively controlled to optimize power or limit loads in response to the conditions.

variable speed: Rotor shaft torque limiting is accomplished by using high voltage electronic components and special generator designs to allow a wide range of rotor speeds. This method utilizes changes in inertial energy in the rotor to absorb the effect of wind gusts.

VAWT: Vertical axis wind turbine. The rotational axis of the rotor is approximately perpendicular to the horizon. This kind of turbine is beyond the scope of this standard.

wind turbine generator system (WTGS): A system that converts the kinetic energy of the wind into electrical power.

wind turbine manufacturer: Entity that designs, manufactures and warrants wind turbines.

wind turbine operator: Entity that operates and maintains wind turbines.

yaw: Rotation of a HAWT's nacelle about the long axis of its tower. Used to orientate the nacelle (rotor disk) with respect to the prevailing wind.

yaw bearing: The bearing system that supports the nacelle in a HAWT. It permits the nacelle to rotate about the tower axis.

yaw drive: The system of components used to cause yaw motion.

3.3 Gearbox terms

alloy steel: Steel containing significant quantities of alloying elements such as nickel, chrome, or molybdenum to improve its properties such as hardenability or toughness.

ambient temperature: The dry bulb air temperature within the immediate vicinity of the gearbox.

annulus gear: Gear wheel with teeth on the inner surface of a cylinder. Also known as an internal gear.

aspect ratio: The ratio of the pinion face width to the pinion operating pitch diameter.

bearing basic rating life: The life where adjustment factors for reliability, material and environment are taken as unity (1.0).